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JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

RECENT TRENDS IN DESIGN AND CONSTRUCTION OF COPPER CONCENTRATORS IN THE SOUTHWEST

BY

C. E. RORK

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RECENT TRENDS IN DESIGN AND CONSTRUCTION OF COPPER CONCENTRATORS IN THE SOUTHWEST[1]

By C. E. Rorke[2]

INTRODUCTION

This paper discusses various mechanical improvements that have been gradually incorporated in the copper-milling plants of the Southwest during the past 14 years, power plants for concentrators, use of large-size units of equipment, and the effect of plant capacities on costs.

The improvements in mechanical equipment and plant design have contributed in the reduction of operating costs; in some instances a saving in the capital cost per ton of daily capacity milled has resulted.

TRANSPORTATION EQUIPMENT

Pan and Apron-Type Ore Feeders

Pan and apron-type ore feeders usually are made of steel-plate pans or plates articulated with each other and mounted on two parallel endless chains provided with rollers at the pitch points and supported by rails. Under the strain of continuous heavy service the replacements of worn wheels and bent pans for feeders of this type have proved costly.

Modern heavy-duty feeders are equipped with heavy, cast manganese-steel plates secured to two endless manganese-steel chains. The chains ride on rollers mounted in pairs on shafts. The plate and chain articulation is so arranged that the chain-joint flexure comes to a stop when the plates are level with each other on the load-carrying side. This action enables the assembly to support the load between rollers. Roller wear has been minimized because the design allows the use of shafts and bearings of ample size and provides for proper lubrication. The manganese-steel plates are rigid, and replacements seldom are required for 2 or 3 years. A saving thus is effected in maintenance costs, and shut-downs due to feeder troubles are virtually eliminated. A feeder of this type is used at the New Cornelia crushing plant of the Phelps Dodge Corporation and at the Sacramento shaft of the Bisbee branch of the same corporation.

1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgement is used: "Reprinted from U.S. Bureau of Mines Information Circular 6866."

2 One of the consulting engineers, U.S. Bureau of Mines.

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Modern pan and apron-type ore feeders of manganese-steel construction are strong enough to resist the impact of falling ore. Capacities usually can be increased 50 percent by increasing the height of the skirt boards and carrying a deeper bed of ore. Apron speeds of these machines are usually 20 to 30 f.p.m. and can be increased 20 percent to gain additional capacity.

Belt Conveyors

The outstanding improvement in the design of belt conveyors in the mills of the Southwest is the use of antifriction idlers. Very few mills are completely equipped with conveyors of this type; in the majority of cases they have been purchased as replacement equipment in the last 5 or 6 years. Compared with the plain-bearing-type conveyor, antifriction idlers have effected a substantial saving in power consumption, maintenance cost, and labor and supplies incident to lubrication.

The plain-type-idler installations require frequent lubrication, whereas one filling of grease in the antifriction type usually suffices for 5 or 6 months.

The power required for level conveyors equipped with anti-friction idlers and bearings is conservatively half that required for those equipped with plain bearings.

Belt conveyors are rated according to the number of cubic feet of ore handled per hour at a belt speed of 100 f.p.m. This amounts to $3.5A^2$, where A is the width of the belt in inches. In actual design, however, the capacity allowance for conveyors traveling at 100 f.p.m. is $3A^2$, providing for an increase of capacity of 16 percent without a change in the speed.

Modern antifriction conveyors can be run at a higher speed than those with plain bearings, when carrying the average sizes of ore. The following maximum speed limitations are advisable.

Size of ore, inches	Maximum speed, f.p.m.
16	200
12	250
6	300
4	400
3/4	600

The tabulation that follows gives the cost per foot of conveyor for belt and idlers only and the percentage increase in capacity over the preceding size. These costs are for average-duty equipment and do not include costs of altering supports or terminal.

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Width of belt, inches	Cost per foot			Increase of capacity percent
	Idlers	Belt	Idlers and belt	
18	$ 9.30	$ 5.25	$ 14.55	--
20	9.40	5.80	15.20	23
24	9.75	6.45	16.20	43
30	10.80	8.65	19.45	56
36	13.80	11.00	24.80	44
42	14.50	13.50	28.00	36
48	15.50	17.00	32.50	30
54	16.75	18.75	35.50	26
60	22.75	21.50	44.20	23

Pumps for Mill Pulps

Centrifugal pumps employed in transporting mill pulps are now built with thick impellers and liners, with provisions for taking up the clearance caused by wear. As wear is unavoidable this arrangement allows a pump to remain in service longer than would otherwise be possible. The wearing parts usually are made of fairly hard cast iron to reduce the cost of renewals.

The principal improvement in these pumps is the outgrowth of more efficient metallurgical practice in the foundry. The wearing parts formerly were made of hard, white iron produced from a mixture of pig, scrap cast iron, and scrap steel. Virtually the same ingredients are used now, but the chemical constituents are balanced carefully to produce an iron of known properties. In consequence, the parts of the pump are tough and strong and have superior wearing qualities. This feature has contributed materially toward reducing maintenance costs.

Failure of the stuffing boxes of sand pumps often causes delay. Designs incorporating improved stuffing boxes, ejectors which replace stuffing boxes, and suction intakes without them are now available.

Bucket Elevators

Many bucket elevators have been replaced by sand pumps in the copper mills of the Southwest. Finer grinding, a practice that is growing in favor, has made these practical, and lower maintenance cost and fewer delays have made the change desirable. However, a survey of recent information circulars published by the United States Bureau of Mines shows that some bucket elevators have been retained in the majority of southwestern copper concentrators, as indicated in the following tabulation:

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Use of bucket elevators in southwestern concentrators

Concentrators	Class of service
Hayden	In coarse crushing plant, fine crushing plant, roll circuits, and handling concentrates.
Cananea	Sampling plant.
Magma	Handling Marcy mill product, table middlings and tailings, and secondary grinding-mill discharge.
Nacozari	Handling concentrates.
Hurley	Coarse crushing, handling grinding-circuit products and concentrates.
Copper Queen	Handling concentrates.
Old Dominion	In coarse crushing plant, 1 of 2 units.
United Verde	No elevators.
Miami	Do.

Belts usually are 8- to 12-ply, with 1/8- to 3/32-inch rubber cover. Standard practice is to have them wide enough to allow a margin of 1 inch on each side of the buckets.

The buckets, manufacturers' standard style A, are of malleable iron with reinforced lips. They are spaced on 12- to 30-inch centers and mounted in single row, double row, or double row staggered, according to the volume of material to be elevated.

The most important recent improvement in belt-and-bucket-elevator practice is the application of enclosed speed reducers for driving, which eliminate undue wear from grit.

Chutes, Launders, and Flumes

The outstanding recent improvement in chutes for dry ore is the use of rubber lining. The rubber liners are of special composition and are 1/4 to 3/4 inch thick, according to the size of ore handled and height of drop.

The greater the impact the thicker the lining required to provide the necessary resilience. Lower costs per ton of ore handled are claimed for such liners when installed properly under the required conditions than for the various irons and steels previously used; these claims have been substantiated in many instances.

The launders now employed are of the same general construction as those used for many years. They are usually built of 2-inch lumber, dressed to 1 5/6 inches, and are 3 1/2, 5 1/2, 7 1/2, 9 1/2, or 11 1/2 inches wide inside.

In the days of gravity concentration the maintenance of launder liners was a problem of considerable importance. With the introduction of flotation requiring finer grinding the cost of maintaining liners has decreased. A comparatively recent innovation is the use of discarded conveyor and elevator belting for launder liners in places where the wear is noticeable.

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The outstanding improvement in the distribution of pulps from the classifier overflows to the flotation machines is the practice of using pipes instead of launders. Flotation middlings also are handled in pipes in many plants. The following copper concentrators of the Southwest, described in information circulars of the Bureau of Mines, use pipes.

Concentrators using pipes for conveying pulps

Concentrator	Service
Copper Queen	Conveying classifier overflow pulps to flotation and rougher concentrate pulps to cleaner cells.
Morenci	Distributing tailing pulps to form dams.
Hurley	Conveying tailing pulps to ponds; 30-inch wooden-stave pipeline 6,590 feet long.
Magma	Conveying concentrate pulp from mill to thickener at smelter; 4-inch-diameter pipeline 2,900 feet long.

TRANSMISSION EQUIPMENT

Belt Drives

Belt drives from line shafts have been giving way to direct motor drives during the last 10 to 12 years; this change has resulted in savings in maintenance costs, economy in power due to higher mechanical efficiency, and reduction in operating hazards.

The short-center belt drive used for the last 8 to 10 years has been popular. In this type of drive the angle of contact of the belt with the smaller pulley is maintained by the use of an idler pulley running on the outside of the belt. This pulley is mounted on a hinged lever arm and is provided with a holder on which to place the proper weight.

Speed-Reducer Units

During the last decade enclosed-gear speed reducers have been used extensively. Previously they were used in only a few mills because they were obtainable only on special order to suit special conditions.

Speed reducers of various sizes and ratings have been developed and are now on the market. They are cataloged in closely consecutive speed ratios ranging from 1:1.5 to 1:1,200 and in horsepower ratings from 1/2 to 250. There are three general types in use: Enclosed worm gearing; enclosed spur, helical, or herringbone gearing; and planetary gear type.

These reducer sets are built in oiltight cases; a charge of oil provides sufficient lubrication for several months. The wearing parts are protected from dirt, and the design conforms to safety regulations.

The mechanical efficiencies are high, approximately 90 to 95 percent on speed ratios of 1 to 20 or 30.

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In the copper mills of the Southwest these speed-reducer sets are used for reducing the comparatively high speeds of electric motors and transmitting the power to ball and rod mills, classifiers, ore feeders, conveyors, and elevators.

Gears with Generated Teeth

Up to 20 years ago millmen were satisfied with plain-cast tooth gearing. Since then the general practice has been to use machine-cut gears, the teeth of which are formed by milling cutters. The shape of these cutters depends on the number of teeth to be cut in the gear; compliance with the market demands for gears of 12 to over 200 teeth in each of the various pitches would require the manufacturer to be equipped with 2 or 3 thousand of these tools. To reduce the number of tools required it became standard practice to use each cutter for forming gears with a range of several steps in the number of teeth; for example, a tool made to cut 50 teeth could be used to make gears of 44 to 56 teeth. This obviously resulted in inaccurate tooth profiles.

Since 1920 machines have been designed to generate a true involute tooth curve on gears of any size or pitch and with any desired tooth angle. Plain spur, helical, and herringbone gears are generated by these modern methods. The generated gears run quietly and smoothly and have an efficiency of 97 percent per pair.

Generated spur gears are used on the 8 1/2-foot ball mills in the Copper Queen and Morenci concentrators of the Phelps Dodge Corporation. These gears have a diametrical pitch of 2 15-inch faces, and the ring gears have 240 teeth. Pinions of 13 and 14 teeth, respectively, are used to change the mill speed. The pinion shafts are connected by flexible couplings to 300 hp. synchronous motors having a speed of 225 r.p.m. The average motor input is around 240 hp.

V-Belt Drives

An efficient transmission device recently designed is the V-belt drive; it consists of two grooved pulleys and one or more endless V-belts. The belts are trapezoidal in cross-section, shaped like a truncated V, with the sloping sides at an angle of about 40° from each other. They are made of cotton fabric and cords impregnated with rubber on a rubber core, the whole being vulcanized in a mold. Various lengths of rope are available to suit different pulley centers. The sheave-groove faces have the same angle (about 40°) as the ropes. Clearance is provided at the groove bottom to give a wedging grip.

These drives are available in capacities of 1/2 to 300 hp. and in reduction ratios of 1:1 to 7:1. Five standard cross-sections of rope are used, ranging from 1/2 by 11/32 inch to 1 1/2 by 1 inch. The number of ropes used on a single drive ranges from 1 to 20.

The advantages of V-belt drives may be summarized as follows: (1) Low maintenance cost; (2) Low first cost; (3) low power loss; (4) silent operation; (5) very short centers although practical without idlers; (6) easy replacement

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of ropes; (7) can be run in either direction and at any angle; (8) speed ratio can be readily changed by changing one pulley; (9) resilience of ropes avoids starting shocks; (10) ultimate slipping of ropes prevents damage if the machine becomes locked.

The cost of V-belt drives can be estimated approximately from the formula: Cost in dollars = $\frac{7{,}200\ R}{S}$ + hp., where R is the drive-speed ratio, S the motor speed in r.p.m., and hp. the horsepower of the motor.

Antifriction Bearings

As with other modern transmission machinery, antifriction bearings are being utilized in the copper concentrators of the Southwest. Three general types of antifriction bearings are in use - balls, conical rollers, and cylindrical rollers. The ball bearings and conical roller bearings absorb both radial and axial thrusts, whereas the cylindrical roller bearings take radial thrust only.

The advantages in the use of these bearings are in the elimination of friction losses and reduction in expense of lubrication.

In addition to the use of these bearings on conveyor equipment, they have been found extremely advantageous as motor bearings. The air gap between the rotor and the stator faces of modern motors is so small that slight wear on the bearings allows the rotor to rub and cause considerable damage. The extremely slow wear of antifriction bearings virtually eliminates this trouble and consequent expense.

These bearings are also commonly used on the pinion shafts of grinding mills and on the bearings of vertical spindle-flotation machines. At Cananea the 6- by 12-foot rod mills have been supported successfully on a roller chain, each chain having 6 rollers mounted on roller bearings.

POWER

Power at reasonable cost is essential to commercial concentrator operation. The average power consumption at 10 copper concentrators in the Southwest is 14.75 kw.-hr. per ton of ore milled. Power is generated by four general methods: Oil-Diesel, oil-steam, gas-steam, and hydroelectric. The use of gas is limited to plants that consume enough power to justify a pipe line from the distributing centers. The use of hydroelectric power is limited to a comparatively small area, as there is not enough power from this source to supply all the needs. Fuel oil burned under boilers or in Diesel engines has been the most economical unrestricted source of power in the Southwest.

Steam Turbines

Steam turbines are the most important prime movers where steam is used to generate power. One advantage in steam power is the flexibility in regard to

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kinds of fuel used, since fuel oil, gas, or coal may be burned.

Higher pressures and superheating in steam turbine plants have resulted in lower unit power costs because of higher thermal efficiency. The older steam-turbine plants used steam at 150 to 175 pounds gage pressure superheated to a final temperature of 450° to 500°. The modern high-pressure plants in the Southwest operate at 350 to 400 pounds gage pressure, superheating to a final temperature of 700°.

The data that follow show typical, direct unit-power costs for 3 turbine plants of different capacities at 90-percent load factor and with fuel oil costing $2 per barrel.

TABLE 1. - Power costs for steam-turbine units

Size of power unit	kw.	1,000	2,000	10,000
Labor	cent	0.155	0.083	0.020
Supplies	do.	.150	.100	.080
Miscellaneous	do.	.050	.045	.040
Fuel	do.[1]	.580	.540	.480
Total cost per kw.-hr.		.935	.768	.620

1 To correct for fuel oil at any other price allow 0.024 cent per kilowatt-hour for each 10-cent variation in the price per barrel.

The installation cost for units as large as 10,000 kw. is about $100 per kilowatt for a complete plant with auxiliaries; the cost is somewhat higher for smaller installations.

Steam pressures up to 1,200 pounds per square inch are used in modern turbine plants; economy, however, is greater in units of large capacity.

Diesel Engines

In the Southwest where oil is the most economic fuel the cost of generating power with Diesel engines is appreciably lower than the cost by other methods. For example, a concentrator having a capacity of 1,200 tons and requiring 15 kw.-hr. per ton of ore milled would require a 1,000-kw. power plant based on 75 percent efficiency. The relative costs of generating this power would be 0.935 and 0.683 cent per kilowatt-hour for steam turbine and Diesel units, respectively (tables 1 and 2). The saving in power with the Diesel unit would be 0.250 cent per kilowatt-hour or $16,000 per year. For a larger plant the saving per unit of power would not be as high; a considerable total yearly saving, however, should be apparent for a plant having a capacity of 10,000 kw.

For milling plants of 50 to 500 tons daily capacity, requiring power plants of 50 to 300 kw. capacity, the Diesel engine is more economical than any other prime mover where oil as fuel is chosen on a heat-cost basis. These engines show very little drop in fuel efficiency down to one half load.

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TABLE 2. - Estimated direct costs of Diesel-electric power based on fuel oil at $2 per barrel and 90-percent load factor

Number of power units	1	1	1	1	1	1	2
Rating ..... kw. ...	75	150	200	500	1,000	1,500	3,000
Power for auxiliaries do. ...	7	10	12	14	25	35	65
Ave. load factor .... percent	90	90	90	90	90	90	90
Total power generated kw. ...	1,620	3,240	4,320	10,800	21,600	32,400	64,800
Net power distributed do. ...	1,470	3,000	4,032	10,464	21,000	31,560	63,240
Chief engineer	0	0	0	0	0	1	1
Head operator	0	1	1	1	1	0	1
Shift operators	3	2	2	2	3	3	3
Repairmen	1	1	1	1	2	2	3
Oilers	0	0	0	0	1	2	3
Power generated per bbl. fuel oil ..... kw.-hr.	380	390	395	430	470	500	500
Operating labor per kw.-hr. ..... cents .	1.020	0.533	0.396	0.167	0.107	0.094	0.052
Repair labor ..... do. ...	.340	.200	.149	.067	.048	.032	.030
Supplies ..... do. ...	.204	.167	.149	.077	.048	.048	.048
Lubrication ..... do. ...	.061	.040	.038	.025	.020	.018	.018
Miscellaneous ..... do. ...	.025	.025	.025	.025	.022	.022	.022
Fuel oil[1/] ..... do. ...	.597	.554	.542	.481	.438	.411	.411
Total .....do. ...	2.247	1.519	1.299	0.842	0.683	0.625	0.581

1/ For each 10-cent variation in price of fuel oil from $2 per barrel make correction of 0.022 cent per kilowatt-hour.

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Estimated direct costs of Diesel-electric power based on 90 percent load factor and fuel oil at $2 per barrel are given in table 2. Fuel consumption of Diesel-electric power units of 75 to 1,500 kw. ratings is presented in figure 1, and unit power costs for Diesel-electric power are given in figure 2.

Figure 2 shows that for plants of less than 300 kw. capacity unit costs rise very abruptly because the operating and repair labor cannot be reduced in proportion to the power generated. For mills requiring less than 75 kw. the power unit should be installed in the mill so that the engine operator may divide his time between the engine and the mill machinery. In this event the power cost should not exceed 2 1/2 to 3 cents per kilowatt-hour with oil at $2 per barrel.

Motor Applications

For milling plants of 500 tons daily capacity and over the prevailing practice in the Southwest is to use alternating current because of the ease of transforming voltages and the fairly high potential practicable; a saving in the cost of conductors is thus effected. A.-c. induction motors are also preferred because they have no commutators and are therefore less affected by dust. Some of the mills in the Southwest are operated on 440-volt a.-c. current, but the arrangement most favored is to operate motors of 50-hp. or more on 2,200 volts and motors of less than 50-hp. on 220 volts. Motors as small as 25 hp. for 2,200 volts may now be purchased.

In concentrators where several squirrel-cage induction motors are used it has been found that some motors operate below full load even though they have been selected with great care. Because of the characteristics of this type of motor such conditions reduce the general power factor of the system. One of the favorite methods of power-factor correction in the Southwest is to use synchronous motors for some of the larger machines. These motors are usually specified for a given load at 80 percent loading power factor, thus allowing capacity to correct a certain portion of the general lagging power factor in the circuit. The following are typical examples of the application of synchronous motors in the Southwest.

Concentrator	Service
New Cornelia	Grinding mills.
Copper Queen	2 of 16 grinding mills.
Morenci	5 of 11 grinding mills and cone crushers.

The old hand-operated-type motor starter is almost obsolete in the Southwest, having been replaced by the remote-control push-button type. In most plants it is forbidden by the safety rules of the operating companies, since the remote-control type is much safer and also protects the motor from injury because of its automatic control of the motor acceleration. A.-c. motors of 10 hp. and less usually are equipped with a simple magnetic switch and are started at full voltage. Above this size the usual equipment includes auto-transformers which apply reduced voltage until the motor speed is sufficient

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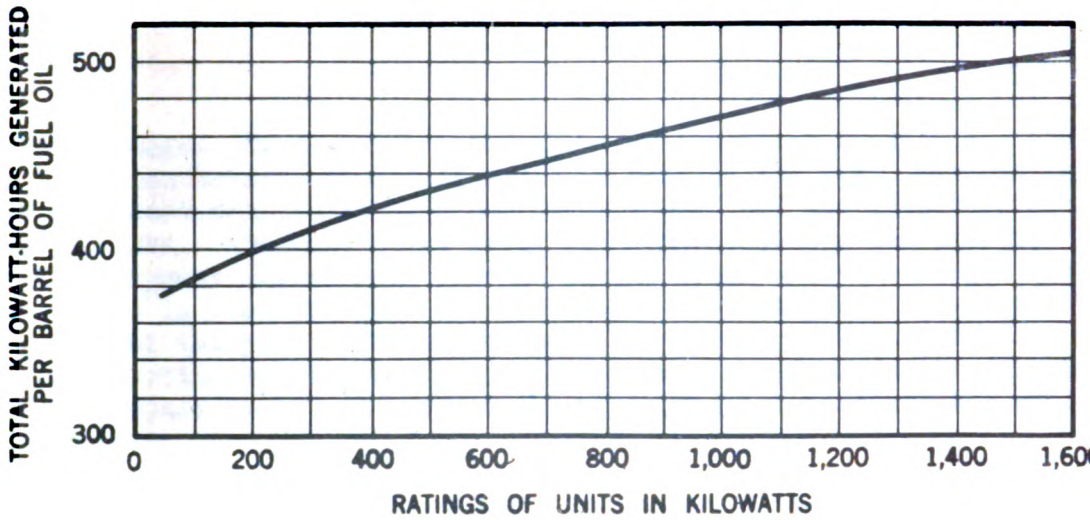

Figure 1.— Fuel consumption of Diesel-electric units, 75 to 1,500 kw. ratings.

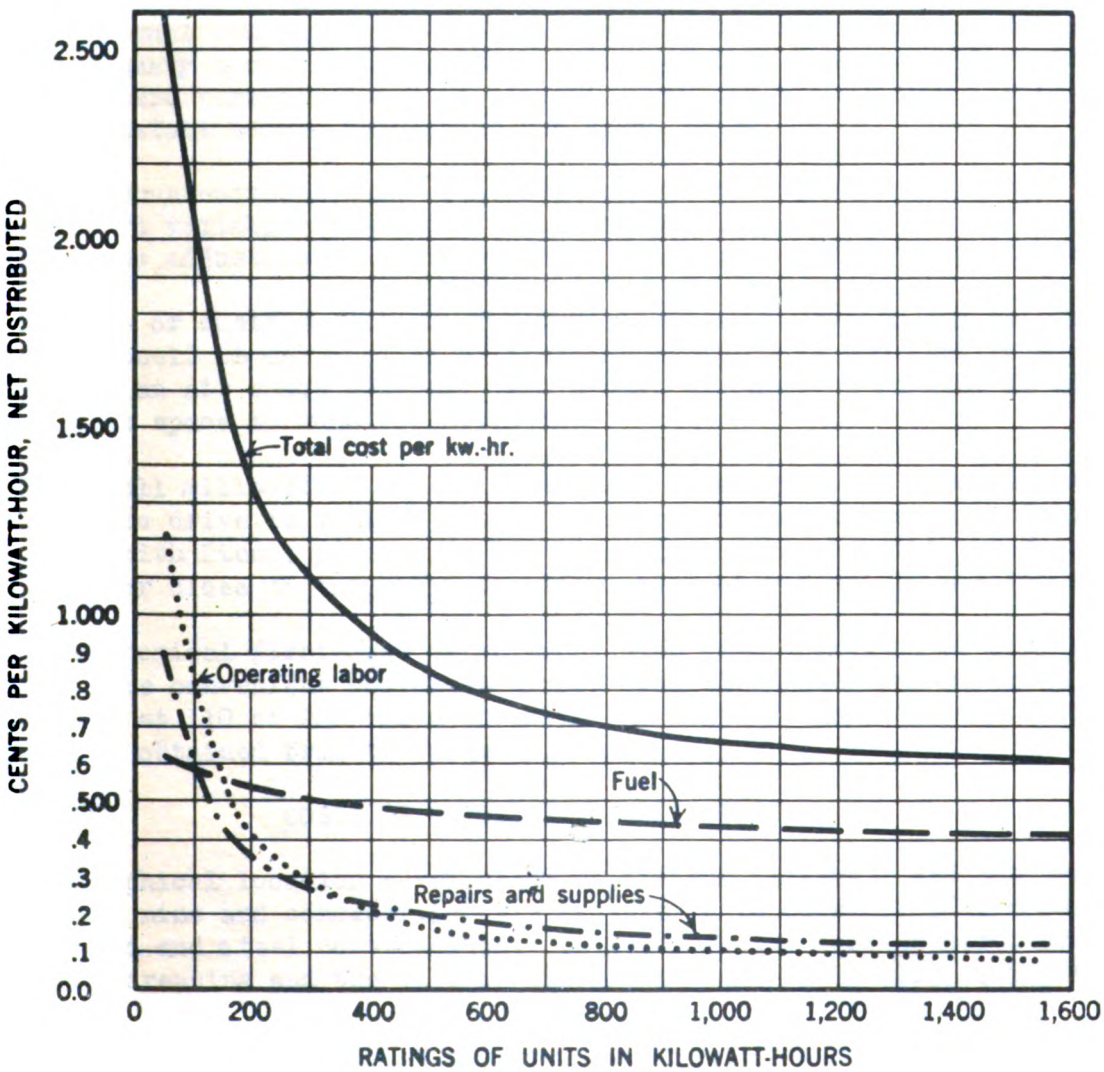

Figure 2.— Unit power costs for Diesel-electric units.

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for full voltage. Synchronous motors have an induction winding and are started as induction motors; when full speed is reached the field circuit is closed, the motor immediately takes on synchronous speed, and the induction windings become inactive. The line-start motor is a comparatively new design; the starting equipment throws full voltage on the motor when starting. The starting equipment is much cheaper, but the motors are not quite as efficient. In consequence of the popularity of the push-button starters the trend is to enclose all starting equipment in dusttight boxes, which aid materially in reducing the repair costs and protect the apparatus and concentrator employees from accidents.

Standard squirrel-cage induction motors have a starting torque of 1.5 to 1.75 times the normal running torque, which is usually sufficient for driving conveyors, centrifugal pumps, blowers, and flotation machines. Where greater starting torque is required the wound-rotor-induction motor, also called slip-ring, is used. These motors can be obtained with a starting torque of 2.5 times the normal running torque. They are used to drive crushing rolls, grinding mills, heavy apron feeders, etc. Motors of this type are also used successfully where variable speed is desired, provided the machine driven requires a constant torque throughout the speed range.

D.-c. shunt-wound motors with field rheostat control are the most satisfactory where variable-speed conditions are exacting, as the relation of definite speeds to adjustment positions of the control is extremely reliable.

For wet or dusty conditions fully enclosed a.-c. motors may be employed. The motor itself is enclosed in a tight casing which is enclosed in another casing with an air space between. Fan blades circulate a current of air through this space to supply ventilation.

For small mills of 50 to 200 tons daily capacity where electric or partial electric drive is desired the d.-c. system is adaptable, especially in connection with Diesel power. As the logical location for the power equipment is at or close to the mill, transformation of voltage is not required.

An economical first-cost arrangement with good operating conditions is to drive some convenient equipment direct from the engine and generate enough d.-c. power at 110 or 220 volts to drive the rest of the machinery. Lighting may then be obtained from the power circuit.

COSTS OF CONCENTRATOR BUILDINGS

Geographical location - reflected in freight charges - and the probable life of the mine and concentrator are factors to be considered in choosing between wood and steel construction. In general, the cost of structural steel has been decreasing and the cost of timber has been increasing during the last 10 years.

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Comparative costs per cubic foot of building for average conditions in the Southwest are presented in the following table. Estimates for structural steel are based on steel at $140 per ton erected and timber-work at $80 per thousand board feet delivered. Designs considered are for conditions in the Southwest.

Comparative cost per cubic foot of mill building for steel and wooden-frame structures

	Steel frame and concrete floors, cents per cubic foot	Wooden frame and wooden floors, cents per cubic foot
Excavations	1.3	1.3
Foundations and walls	2.0	2.0
Floors	1.2	.7
Building frame	8.4	6.9
Corrugated steel roof and sides, windows	.6	.6
Total	13.5	11.5

In erecting concentrator buildings there are so many items with fixed costs that the saving by wood construction is a small percentage of the whole. In a building required for a concentrator of 1,000 tons capacity the net saving of wood over steel construction would amount to approximately $5,000 and for a concentrator of 100 tons capacity, about $800. Approximately 1 ton of steel frame will be required for each 1,660 cubic feet of building, or 1,000 board feet of timber frame will be required for each 1,160 cubic feet.

ADVANTAGES OF LARGE-CAPACITY UNITS

Initial Costs

The advantages of large-capacity units for concentrating plants have been demonstrated recently in the Southwest by the changes and substitutions made from time to time to increase capacity.

In one concentrator having a capacity of 4,000 tons per day the following represents the original cost exclusive of the power plant:

Excavations and concrete	$ 650,000
Buildings and structures	600,000
Equipment	2,522,000
Total	$3,772,000
Cost per ton of daily capacity	$ 943

Had larger ball mills, classifiers, and flotation machines been installed at the time of construction the daily capacity could have been 6,000 tons at an additional cost of $950,000. The total cost would have been $4,722,000

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or $787 per ton daily capacity. In this particular instance, if a capacity of only 4,000 tons was desired, the saving gained by large-capacity units would be about $300,000 and the resulting cost per ton of daily capacity, $868.

The comparison that follows shows the general effect of large-capacity units on floor space. A mill section with a capacity of 500 tons contains two 6 1/2-foot-diameter grinding mills carrying a combined grinding-media load of 60,000 pounds. The dimensions of the section are 27 by 140 feet or a floor area of 3,780 square feet. The area per ton of daily grinding capacity is 75.68 square feet.

A design for a 1,000-ton section on the same class of ore has 2 grinding mills carrying a combined grinding-media load of 120,000 pounds. The dimensions of the section are 32 by 166 feet, which allow for the required increase in size of classifier and flotation equipment. The floor area per ton of daily capacity is 53.12 square feet. These figures indicate a saving of 29.52 percent of floor space per ton gained by doubling the capacity of the essential units of equipment.

Maintenance Costs

The number of moving parts in a concentrator for a given tonnage can be reduced materially through the use of high-capacity modern equipment. The number of repairs and replacements usually is proportionate to the number of machines used; although the cost of renewals is a little higher than for smaller units, it is not over 50 percent more than for a machine of half the capacity. A reduction is thus effected in the cost of labor and supplies for maintenance in the operation of large-capacity units. The cost of repair labor and supplies ranges from $0.04 to $0.10 per ton of ore milled for large and small concnetrators, respectively; the probable saving due to the use of large-capacity units alone is $0.01 to $0.03 per ton of ore treated.

Operating Labor Costs

Under conditions that allow enough margin operating labor costs can be reduced noticeably by the use of large-capacity units. For example, if a proposed concentrator is to be equipped with 3 grinding units which could be replaced by 2, then either arrangement would require 1 man per shift. However, if 12 grinding units, requiring 2 men per shift, could be replaced by 8 larger units, there would be a possible saving of 1 man per shift.

EFFECT OF PLANT CAPACITY ON COSTS

Initial Costs

The data that follow have been computed on the assumption that large-capacity units are used.

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Nominal daily capacity, tons	Initial cost per ton daily capacity
20,000	$ 550
10,000	625
5,000	675
2,500	690
1,000	700
500	710

The cost of coarse-crushing and conveying equipment for large plants is much less per ton than for the smaller installations. Small plants require 1 coarse crusher and 1 intermediate machine; although larger plants require larger units, the cost per ton of capacity is less. Shop building, tools, assay office, and administration buildings for larger plants also cost much less per ton of capacity than for smaller plants.

Operating Costs

Plant capacity influences operating costs more than any other single item. The tabulations of costs shown in table 3 are typical of the Southwest but do not represent figures taken from particular plants. Power costs are based on 0.5 cent per kilowatt-hour, graded up to 0.7 cent for the small plants. Power consumption is assumed at 15 kw.-hr. per ton milled. New water is taken at 300 gallons per ton of ore milled and at a cost of 5 cents per thousand gallons. Labor and commodity prices are the average for 1930.

TABLE 3. - Typical unit operating costs for copper concentrators of the Southwest

Daily concentrator capacity, tons	20,000	10,000	5,000	2,500	1,000	500
Operating labor	$0.040	$0.070	$0.100	$0.140	$0.210	$0.250
Repair labor	.020	.038	.050	.070	.085	.100
General department labor	.015	.025	.035	.055	.080	.100
General department supplies	.005	.008	.012	.015	.027	.035
Operating supplies	.110	.110	.110	.111	.122	.125
Repair supplies	.010	.010	.010	.011	.011	.012
Sampling and assaying	.005	.008	.015	.020	.030	.035
Power	.075	.075	.075	.090	.100	.110
Water	.015	.015	.015	.015	.020	.025
Total	$0.295	$0.359	$0.422	$0.527	$0.685	$0.788

As shown in table 3, general department expense and operating labor contribute mainly to the higher operating costs for the smaller-capacity plants. Even the smallest plant shows administration expense, as it must have a superintendent, master mechanic, and chief chemist. Operating labor must be supplied for crushing, grinding, and concentrating; if the plant capacity was increased within certain limits, the operating labor provided for the smaller plant would be sufficient to operate the large unit.

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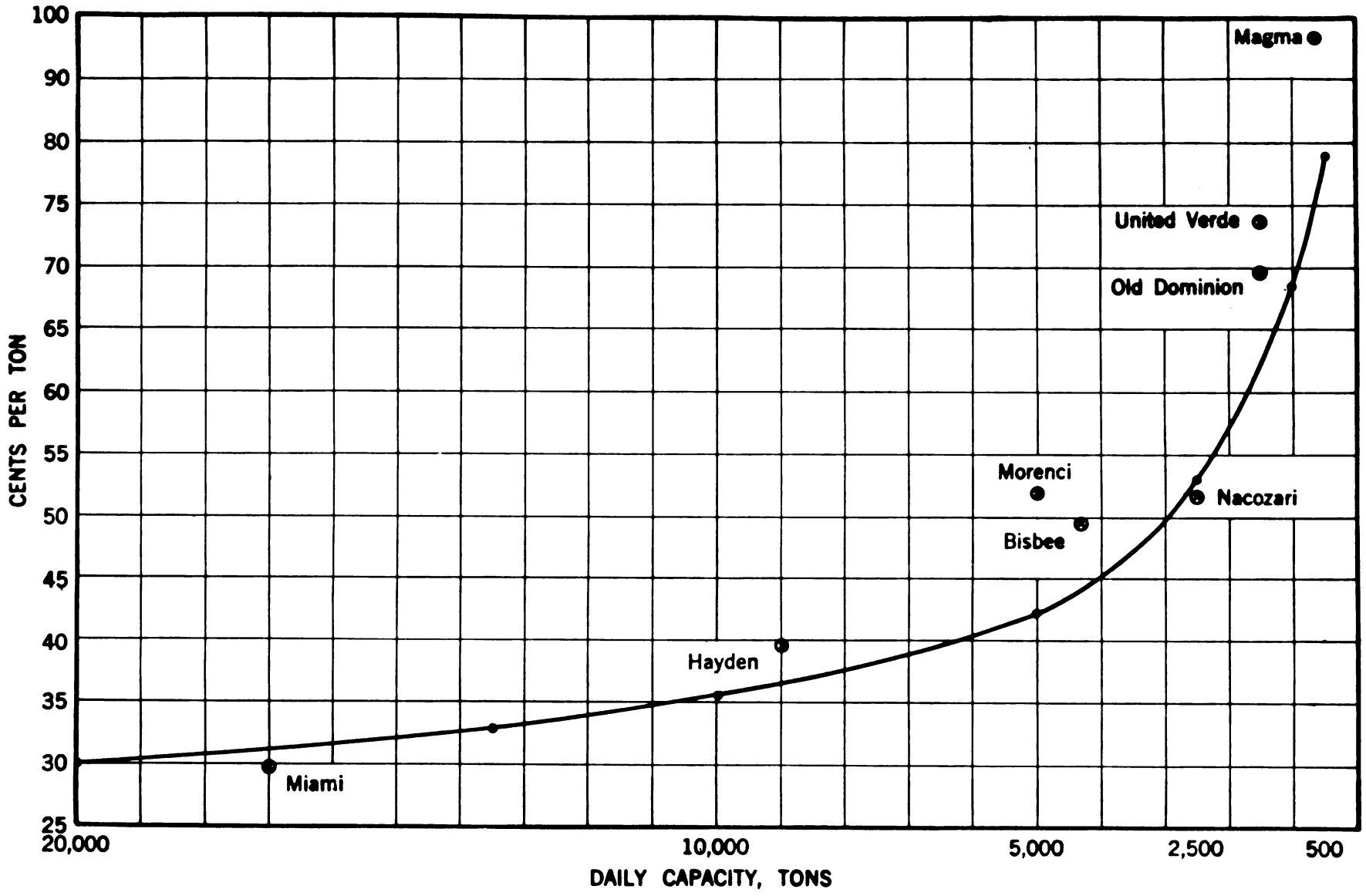

Figure 3.— Variation of unit milling costs with plant capacities and comparison with costs obtained at copper concentrators in the Southwest.

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When units costs at the Southwestern Copper Concentrator are plotted against daily capacities the agreement is remarkably close, despite variation in the costs of the different elements. By making adjustments to suit prevailing prices, a curve can be obtained to show a very close approximation of expected operating costs at any given daily capacity.

A curve showing the variation of unit concentrating costs with plant capacities is given in figure 3. Typical southwestern operating costs are also shown in figure 3 for comparison.

CONCLUSION

The use of modern mechanical equipment in a well-designed assembly and of large-capacity units have been the means of lowering initial and operating costs at copper concentrators in the Southwest.

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